Five-Year Research Summary Using PAM in Furrow Irrigation

R. D. Lentz and R. E. Sojka

A previous conference paper (Sojka and Lentz, 1996) presented an historic perspective and some general results of PAM investigations conducted at the USDA-ARS Northwest Irrigation and Soils Research Laboratory in Kimberly, Idaho. This paper presents the experimental methods and summarizes results from those studies, conducted over a five-year period.

Studies initiated since 1991 determined best mode of PAM application, established PAM's effectiveness under different furrow irrigation scenarios and sought to define its potential environmental impacts *(Lentz, et al., 1992; Sojka and Lentz, 1993, Sojka et al., 1994; Lentz, 1996; Trout et al., 1995)*. Kimberly ARS field experiments initially sought to determine the PAM application method that most efficiently and effectively controlled furrow-irrigation induced soil loss and infiltration. We investigated the following PAM application parameters:

PAM form — dry granular, stock solution, oil emulsion

PAM type — polymer charge type, charge density, molecular weight

Application method — standard: PAM added to irrigation water; non-standard: PAM applied to furrow soil

Application strategy — timing, rate, and period of PAM application

Irrigation water quality —effect of a water's total salt or sodium adsorption ratio on PAM effectiveness

Experiments that examined effects of PAM type on furrow processes are presented in a separate paper *(Lentz and Sojka, 1996)*. A series of studies documented PAM's usefulness over a range of furrow-irrigated field conditions. PAM was tested on different soils, furrow slopes, and using different furrow inflow rates and irrigation waters. Several studies examined PAM's environmental impacts. We first developed an analytical procedure for measuring PAM concentration in irrigation water to document the fate of PAM applied to furrow irrigation inflows. A permanent PAM field site was established to study effects of long-term PAM applications on soil properties, microbiology *(Watwood and Kay-Shoemake, 1996)*, productivity and solute leaching. Another experiment documented PAM s influence on field runoff water-quality. Finally, a plot treated with excessive PAM additions was used to determine the potential for acrylamide-monomer accumulation in crop-tissue *(Barvenik et al., 1996)*.

Materials and methods

Field studies were conducted at the USDA-ARS Northwest Irrigation and Soils Research Laboratory at Kimberly, ID, and on fields of cooperating farmers near Filer, Hansen and Emmett, ID. Soils included Durixerollic Calciorthids, Xerollic Haplargids, and Haploxerollic Durargids. Surface soils in these studies were similar, though subsoils varied among sites. Surface soil textures were silt loams (10-21% clay, 60-75% silt), organic matter was 10-13 g kg^{-1}, cation exchange capacity was 18-20 $cmol_c$ kg^{-1}, electrical conductivity (EC, saturated paste extract) was 0.7-1.3 dS m^{-1}, ESP was 1.4-1.7, pH was 7.6-8.0 and calcium carbonate equivalent varied from 2-8%. Slopes were 0.5-7.0%. Seedbeds were disked or moldboard plowed, then roller-harrowed, and planted to corn *(Zea mays)*, field beans *(Phaseolus vulgaris)* or potato *(Solanum tuberosum)*. Row spacing was 0.56 m (22 in) for beans, 0.76 m (30 in) for corn and 0.92 m (36 in) for potatoes. Electrical conductivity of irrigation water was 0.1 at Emmett and 0.5 dS m^{-1} at Kimberly, Filer and Hansen, and SAR was 0.4-0.7.

Furrows were shaped with a weighted furrow-forming tool. Only the alternate wheel-trafficked furrows were monitored in each study. Irrigation water was applied from adjustable spigots on gated pipe or syphon tubes set in concrete head ditches. Furrow lengths were 175-264 m (570-860 ft). Irrigation duration was 8-12 h. Inflow rates were 13-38 L min^{-1} (3.5-10 gpm) during furrow advance, with highest rates on gentle slopes; subsequent inflows were reduced to 13-23 L min^{-1} (3.5-6 gpm) when feasible.

Most studies employed a high molecular weight anionic PAM with moderate charge density, manufactured and marketed under the trade name Superfloc 836A by CYTEC Industries, Wayne, NJ. Superfloc 836A is a white granular material with a crystal size slightly larger than ordinary table salt. The granular PAM was used to prepare a 1200 or 2400 g m^{-3} (1200 or 2400 ppm) aqueous stock solution. During solution preparation, a motorized propeller vigorously stirred water into which granules were slowly sprinkled. Mixing continued for at least 20 min and the solution was allowed to stand a day or two to fully disperse. An emulsified form of this anionic PAM was also supplied by CYTEC. A stock solution was prepared from the PAM emulsion in a two-step dilution process. A 1% solution was mixed by slowly pouring the emulsion into a water-filled tank, along the edge of a vortex created in the water by a rapidly turning propeller. The 1% solution was then diluted to 1200 g m^{-3} (1200 ppm) using a similar protocol. Stock solutions were mixed using tap water having an EC = 0.9 dS m^{-1} and a SAR = 1.5.

Fig. 1 PAM application strategies employed in various studies

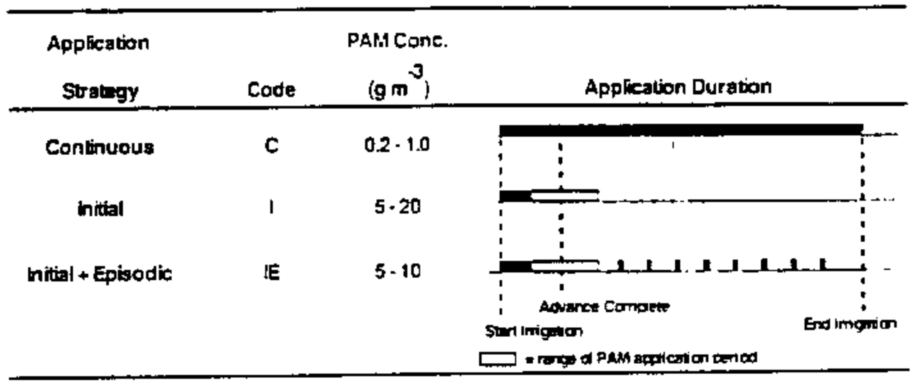


Table 1. Standard PAM treatments (PAM added to irrigation water).

Treatment Code	Timing, duration, and rate of PAM applied
$C_{0.25}$, $C_{0.5}$	Continuous PAM solution injection at 0.25 or 0.5 g m^{-3} (0.25 or 0.5 ppm) throughout the irrigation
$I_{5\text{-}20,\,100\%}$	Initial. PAM solution injection at 5-20 g m^{-3} (5-20 ppm) during the entire furrow advance (100%) and sometimes for an additional 30-90 min (110%+ advance)
$IE_{5\text{-}10,\,100\%}$	Initial-Episodic. PAM solution injection at 5-10 g m^{-3} (5-10 ppm) during furrow advance or for an extra 30-90 min (110%+ of advance) **plus** additional episodic/intermittent short-term applications made subsequent to the initial dose. Episodic applications were 5-15 min in duration at 5-10 g m^{-3} (5-10 ppm) PAM, applied every 1-4 h.
Dry $I_{10,\,100\%}$	Initial. PAM granules additions at 5-20 g m^{-3} (5-20 ppm) during furrow advance and somet imes for an additional 30-90 min (110%+ of advance);

Furrow infiltration and soil-loss studies were randomized with three-six replications. PAM application procedures and furrow monitoring procedures were identical to those of Lentz et al. (1992). Positive displacement pumps metered stock solutions into the head of each furrow, at the position where turbulence from incoming water produced rapid mixing. We periodically monitored furrow inflows, measured outflows with long-throated flumes and determined runoff sediment content (Imhoff cone technique) during the irrigation *(Lentz et al., 1992)*. Soil loss and infiltration were computed from field data with FUROFIGR, an analytical computer program *(Lentz and Sojka, 1994b; Sojka et al., 1994)*. Soil loss reduction was given as a percent and calculated as follows: 100 x (control - PAM-treated) / control. Net-nfiltration increase was calculated with: 100 x (PAM-treated - control) / control.

Runoff water quality was assessed during several irrigations. Samples were taken from outflow monitoring flumes. We measured sample electrical conductivity, EC *(Robbins and Wiegand, 1990)*, Total-P *(Greenberg et al., 1992)*, Ortho-P *(Watanabe and Olsen, 1965)*, Chemical oxygen demand , COD *(American Public Health Association, et al., 1971)*, and NO_3-N (2.0 mM potassium benzoate eluent and liquid ion chromatography). Three samples were collected at 1-2 h, 5-6 h, and 8-10 h into each irrigation.

PAM Treatments. Standard PAM application treatments applied PAM to irrigation water, either as a stock solution, or as dry granules. PAM was applied continuously, or for a specified period, starting when inflow began and continuing until the water first traversed the dry furrow (advance phase), or slightly longer. Three standard PAM application strategies were developed by varying the rate and timing of the stock solution application (Fig. 1, Table 1). Treatment codes indicate timing, concentration, and duration of application, where duration is given as the percent of the furrow advance treated. A fourth strategy applied PAM to the irrigation water as granules instead of a stock solution (Table 1).

Non-standard PAM application treatments applied PAM to furrow soils rather than irrigation water (Table 2). PAM was applied to furrows as a spray or broadcast in the upper furrow section.

PAM/water-quality interactions pertaining to infiltration were examined with a recirculating furrow infiltrometer. Kimberly (Snake R.) irrigation water was used as the low EC/low SAR source. Other water quality treatments were produced by increasing the EC and/or sodium adsorption ratio (SAR) of the Kimberly water with additions of NaCL, NaOH, or $CaCl_2$ salts. The four waters represented different combinations of low and high EC, and low and high SAR. Approximate treatment-water ECs were either 0.6 or 2 dS m^{-1}, and SARs were either 0.7 or 9. Each source water was amended with 0.25 g m^{-3} (0.25 ppm) PAM before water entered to infiltrometer. Hence, the PAM treatment was analogous to a $C_{0.25}$.

PAM-inflow interactions. This study examined the effect of doubling irrigation inflows from 23 to 46 L min^{-1} (6 to 12 gpm) on PAM-I_{10} treatment efficacy. The crop was potatoes. Furrows were 138 m (450 ft) long, with a slope 1.4%. Control and I_{10}-treated furrows at two inflow rates were monitored during an entire season.

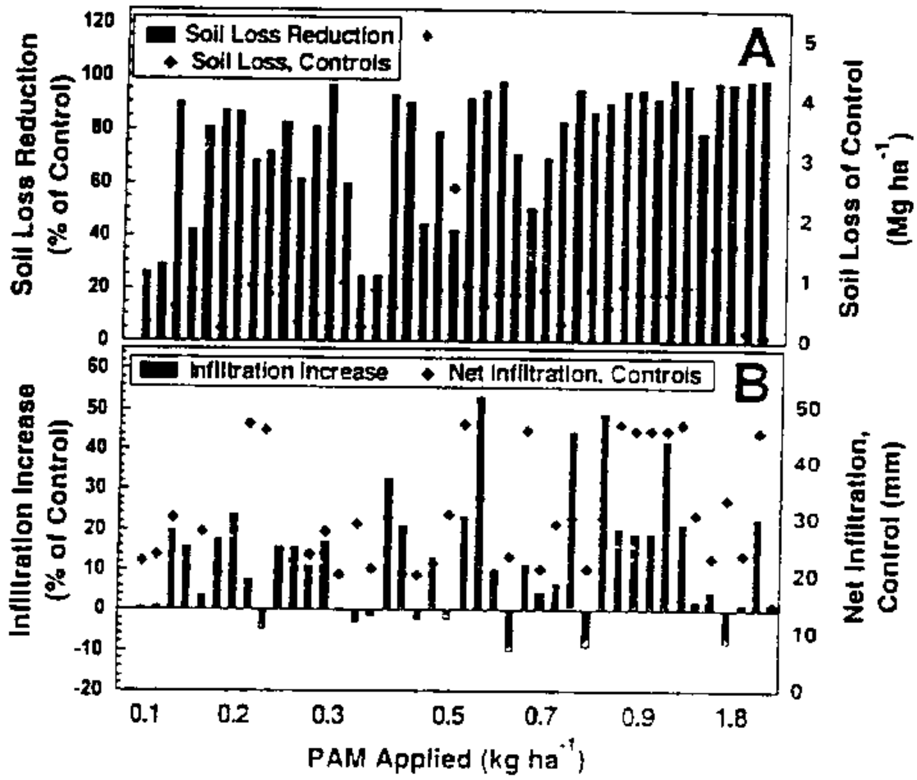
Determination of PAM in irrigation water was accomplished with an instrumented flocculation (CSI) test developed at the Kimberly ARS Research Laboratory *(Lentz et al., 1996)*. The procedure adds a standard clay mineral to a PAM-amended water sample, which is agitated, then placed in a spectrophotometer. Flocculation and settling in the suspension as function of transmitted light is monitored over time. PAM concentration was correlated with settling-related transmittance changes. The procedure can detect as little as 0.1 g m^{-3} (0.1 ppm) PAM dissolved in irrigation water. Accuracy of the test ranges from ±0.06 to 0.11 g m^{-3} (ppm) for 0-2.5 g m^{-3} PAM and ±0.39 to 0.86 g m^{-3} for 2.5-10.0 g m^{-3} PAM. The CSI test provides a relatively simple, rapid, and accurate method for determining polyacrylamide in surface waters.

PAM-Fate Studies. PAM fate was examined by measuring in-stream PAM concentrations in furrows and in tail- and waste-water streams that conveyed runoff away from the field *(Lentz et al., 1995)*. The wastewater stream may also receive tailwater contributions from neighboring fields. PAM treatments included an I_{10} (10 g m^{-3} or 10 ppm PAM applied only as water first advanced down-furrow) and C_1 (1 g m^{-3} or 1 ppm PAM applied during the entire irrigation). The Dry I_{10} granular-PAM vs I_{10} treatments were also compared. Furrow-stream samples were collected at upper, mid, and lower positions along the 175 m furrows and a 200 m wastewater ditch that received the field runoff. Samples were taken 0.2 h (prior to curtailment of PAM application in

Table 2. Non-Standard PAM treatments (PAM applied to furrow soils).

Treatment Code	Timing, duration, and rate of PAM applied
Spray	Sprayed same amount of PAM equal to that provided by I_{10}, ie. ~1.1 kg ha^{-1} (1lb ac^{-1}). Thus, 37.8 L (10 gal) of 600 g m^{-3} (600 ppm) PAM stock solution was sprayed onto each 175 m (575 ft) long furrow.
BrdCst	Broadcast an amount of PAM granules equivalent to that of I_{10} along upper 30.5 m (100 ft) of furrow. Total PAM applied: 22.7 g (0.8 oz) for 175 m (575 ft) long furrow

Fig. 2 Control values and PAM-induced sediment-loss reductions (A) and net infiltration increases (B) are reported for treated irrigations or freshly cultivated furrows. Within each group, treatment parameters were identical, but PAM application strategy, irrigation duration, inflow rates and furrow slope varied between groups.



high-load treatments), ~2 h, and 7 h after the irrigation started.

Results and Discussion

Standard treatment effects. Results from three years study (Fig. 2) indicate that at least 0.7 kg ha^{-1} (0.63 lb ac^{-1}) PAM should be applied during irrigation to produce consistently good erosion control. Lower application rates were effective under certain soil, field, or environmental conditions, but results were more variable. When the optimal application rate was used, PAM reduced furrow soil loss by an average of 94%, with reductions for individual irrigations ranging from 80-99%. Furrow infiltration varied appreciably from furrow to furrow, and PAM's influence on infiltration reflected this pattern. When > 0.7 kg ha^{-1} (0.63 lb ac^{-1}) was applied, PAM produced an average net-infiltration increase of 15% (relative to controls), but for individual irrigations, the infiltration-increase ranged from -10 to 51%.

Other PAM application parameters—timing, duration and furrow stream concentration—also influenced PAM's erosion and infiltration management potential. The most effective treatments, $IE_{5\,100\%}$ and $I_{10\,100\%}$, applied 5-10 ppm PAM during the entire furrow advance (Table 3). The $IE_{5\,100\%}$ approach proved to be most efficient, giving maximum soil protection and infiltration benefits while using half the PAM required by the $I_{10\,100\%}$. Continuous PAM applications at < 1 g m^{-3} (< 1 ppm) provided about 75% the control for one-fourth to one-seventh the cost of the best treatments.

Erosion-control efficacy of solution- and dry-PAM application treatments was similar (Table 4). The average seasonal soil loss reduction was 84.3% for the dry-PAM application and 91.5% for the PAM solution treatment, although, differences were not significant ($p = 0.27$). An emerging trend among individual irrigations indicated the solution approach produced greater or equal soil-loss reduction than the dry method. In addition, dry PAM granules applied to the gated-pipe water stream did not completely hydrate and disperse. At season's end, partially hydrated slimy masses of PAM were discovered in the gated supply pipe, indicating an incomplete and inefficient use of the applied PAM. Emulsion PAM, used to prepare a stock solution which was then applied as $I_{10\,100\%}$ treatments, was as effective for furrow irrigation management as the other PAM forms (data not shown).

Table 3. Soil-loss reduction and increased net infiltration from PAM treatments, relative to control values. Average soil loss in control furrows was 0.9 Mg ha^{-1} (0.8 ton ac^{-1}) and net infiltration was 39 mm (1.5 in.). Treatments were applied to new furrows and control soil losses were similar among the 12 h irrigations.

PAM Treatment Code (PAM applied, kg ha^{-1})	$C_{0.25}$ (0.15)	$IE_{5\,60\%}$ (0.45)	$IE_{5\,100\%}$ (0.55)	$I_{10\,100\%}$ (1.15)
Soil Loss Reduction, %	77.7	82.8	94.8	93.7
(SD, %)	(3.1)	(12.2)	(3.4)	(2.7)
Net Infiltration Increase, %	12.8	15.8	17.6	19.5
(SD, %)	(5.4)	(0.3)	(5.8)	(15)

Table 4 Seasonal sediment loss reduction (% of Control) for solution and dry granular application strategies.

Parameter	PAM Treatment Solution		Dry	
	Mean	SD*	Mean	SD*
Mean	91.5	3.0	84.3	9.7

*SD = standard deviation

Nonstandard PAM applications varied in their effectiveness. Spraying a 38 L (10 gal) of 600 ppm PAM solution on furrows was only moderately effective for controlling soil loss. Therefore, we doubled the application rate in the second irrigation. Results were similar in irrigation two, so spray data were reported as the mean of both runs. The spray treatment reduced soil loss in treated furrows by 33%, relative to controls, and had no effect on net furrow infiltration. The spray treatments disappointing performance might be improved by increasing the PAM application rate 10-fold *(Fox and Bryan, 1992)* or by applying a larger volume of a more dilute PAM solution *(Roa, 1996; this proceedings)*.

Broadcasting 22.7 g granular PAM along the upper 30.5 m (100 ft) of furrows did a good job controlling soil loss, and significantly increased net infiltration into furrows. The BrdCst treatment reduced soil loss 71% relative to controls, compared to the 86% reduction produced by the standard I_{10} approach. Notably, only the BrdCst treatment increased furrow net-infiltration, by 32%, over that of the controls. The reason for this is not entirely clear. Concentrating the PAM in the upper furrow may better stabilize those soils in that reach of the furrow that has the greatest opportunity time and infiltration potential.

Runoff water quality. The I_{10} PAM treatment decidedly reduced sediment, ortho-P, total-P and COD of treated furrow tailwater, but had little influence on runoff nitrate concentrations. The PAM I_{10} treatment reduced soil loss an average 91% each irrigation compared to control furrows. Total seasonal soil loss was 3.14 Mg ha^{-1} (1.4 T ac^{-1}) for control furrows and 0.35 Mg ha^{-1} (0.2 T ac^{-1}) for the I_{10} furrows. Tailwater ortho-P and total-P concentrations in control furrows were five to seven times that of the I_{10} PAM treatment, and control COD levels were four times those of the I_{10} treatment (Fig. 3). PAM also reduced runoff by 26%. Hence, the total nutrient losses from PAM-treated furrows were proportionally smaller than runoff concentration values suggest.

PAM-inflow. Doubling irrigation inflows from 23 to 46 L min^{-1} (6 to 12 gpm) tripled soil losses in untreated furrows but did not apprecia-

Table 5. Soil loss and net infiltration for the standard I_{10} vs. two nonstandard PAM applications, Spray and broadcast (BrdCst). Irrigations were on newly formed 176-m (577-ft) furrows. (n=6 to 9)

Parameter	PAM Treatment			
	Standard		Nonstandard	
	Control	I_{10}	Spray	BrdCst
Soil-loss (Mg ha^{-1})	2.31 c*	0.33 a	1.54 b	0.66 ab
Net Infiltration (mm)	2.90 a	3.14 ab	2.70 a	3.83 c

*similar letters across rows indicate nonsignificant differences ($P < 0.05$).

Table 6. Mean soil loss per irrigation from furrows irrigated with typical inflows (23 L min-1 or 6 gpm) vs. doubled inflows (46 L min-1 or 12 gpm).

Parameter	PAM Treatment			
	1x Inflow		2x Inflow	
	Control	I_{10}	Control	I_{10}
Soil-loss (Mg ha^{-1})	0.64	0.08	1.90	0.15
(Standard Deviation)	(0.2)	(0.15)	(0.1)	(0.1)

bly change PAM's erosion control effectiveness (Table 6). Seasonal soil loss reduction was 89% for the 1x-inflow treatment and 93% for the 2x-inflow rate, and the difference was not significant. Thus PAM gives furrow irrigators a new option, they can increase furrow inflows, permitting more uniform water applications and potentially improving crop quality and productivity. Without PAM, inceasing furrow inflows caused intolerable furrow erosion.

PAM/water-quality interactions. The influence of irrigation-water EC and SAR was observed in both the furrow infiltration rate and cumulative infiltration. Increasing the SAR of $C_{0.25}$-amended Snake River inflows (low EC/low SAR source), from 0.7 to 9 resulted in decreased infiltration rates (Fig 4). Increasing the EC of Snake River water tended to produce higher infiltration rates for PAM-treated $C_{0.25}$ waters, although EC effects varied depending on the water's SAR. Our results suggest that changes in water quality will influence PAM's irrigation impacts. Since water quality can differ appreciably depending on source, geographic location and season-of-use, source-water chemistry should be a consideration in any PAM-application program.

Fate of applied PAM. PAM concentration in treated furrow runoff and tailwater depended upon the form of PAM applied (dry vs. solution), application strategy, time during the irrigation and sequence of irrigation. Note that noncontinuous PAM treatments in these two studies were longer than typical, ie. extended beyond furrow advance, so that all furrows could be measured simultaneously during the later sampling times, and to provide more uniform tailwater conditions among the irrigations.

Although both dry and solution PAM applications did an excellent job controlling erosion, PAM losses for the two treatments differed appreciably. PAM runoff losses of Dry $I_{10, 170\%}$ were 5% of the total applied, compared to 3% losses for the solution $I_{10, 170\%}$ treatment. If only the furrow advance had been treated, PAM losses for the solution I_{10} would have been 1%, compared to 3% for the Dry I_{10} treatment. Hence, the PAM application recommended in the National Resource Conservation Service Practice Standard, solution $I_{10, 100\%}$, did produce the least PAM loss. During PAM injection, runoff from solution-treated furrows contained 6-10 g m^{-3} (ppm) PAM, while runoff from Dry I_{10} furrows contained 1-6 g m^{-3} (ppm). Despite the lower PAM concentration, total PAM losses were greater in Dry I_{10} furrows. The dry PAM added to the Dry I_{10} gated pipe apparently did not completely dissolve. This explains why PAM concentrations were lower in the Dry I_{10} furrow streams than in the solution-treated streams during application. The undissolved PAM masses present in the Dry I_{10} gated pipe continued supplying PAM to the flows, even after the dry PAM application had ceased. Thus, PAM was lost in Dry I_{10} runoff throughout the entire irrigation.

In early irrigations on newly formed furrows, and while injection was occurring, the dissolved PAM-content in C_1 furrow-streams declined with distance downstream, whereas, PAM concentration in I_{10} furrow streams decreased only slightly with downstream distance (Fig. 5). In later sets on previously irrigated furrows, this PAM-decline with distance was more gradual for C_1 furrows, but remained similar to early irrigations for I_{10} furrows (Fig. 6). Within one-half hour after PAM injection in I_{10} furrows ceased, the dissolved PAM concentration in furrow streams had decreased to < 0.25 g m^{-3} (ppm). This was true for both new and repeat irrigated furrows. There was some indication in one irrigation that I_{10} stream PAM-content increased slightly late in the irrigation (Fig. 5). No PAM was being applied at this time, indicating that either this was a sampling or analytical error, or that previously applied PAM was being released back into the stream. Yet, PAM is irreversibly adsorbed to soil *(Malik et al., 1991)*. Perhaps more PAM was applied to furrows than was required to saturate the soil surface. The excess polymer may have temporarily bonded to the PAM already coating the furrow perimeter, only to be released later in the irrigation set.

In the tailwater ditch, flows from I_{10}, C_1, and control furrows mixed together. The combined flows in the early irrigation resulted in a PAM concentration of about 0.5 g m^{-3} (ppm) at the tail-ditch top (Fig. 5). If this was a dilution effect only, the concentration should have been at least 3 g m^{-3} (ppm). Apparently, aqueous PAM was binding to, and flocculating the sediment contributed by control furrows, and hence was removed from the flow. Data from tail and waste water ditches indicate that, early in the irrigations, relatively higher PAM inflow concentrations drop to zero with distance downstream (Figs. 5 & 6). But, as the season progresses, the rate of decrease with distance declines (Fig 6). Thus, PAM concentration in the tail ditch had dropped below the mean detection limit at a point 93 m (300 ft) downstream of the field early in the season, and 530 m (1700 ft) downstream, late in the season.

Conclusions

PAM is an excellent soil erosion deterrent for furrow irrigated fields. It is a cost effective and safe technology, when used at the rates employed in these studies, and greatly reduces both sediment and chemical loading in agricultural runoff. The PAM employed was a moderate-charge-density (18% hydrolysis) anionic form with a molecular weight of 12-15 Mg mol^{-1}. When applied at rates greater than 0.7 kg ha^{-1}, PAM-treated irrigation water reduced furrow soil loss by an average 94% (80-99%) and increased net infiltration by an average 15%. Consistent control occurred when application rates were above 0.7 kg ha^{-1}. PAM reduced soil erosion losses well below soil-loss-tolerance limits on slopes ranging from 0.5 - 3.5%. A very effective approach added 10 g m^{-3} PAM to the irrigation water at the start of the set, continuing during or slightly beyond the furrow advance period.

Acknowledgements

This work was supported in part by the Cooperative Research and Development Agreement with CYTEC Industries under contract 58-3K95-4-216.

Fig. 3 Total-P (A), Ortho-P (B), NO_3-N (C) and chemical oxygen demand, COD (D) concentrations in runoff water from control and PAM I_{10}-treated furrows.

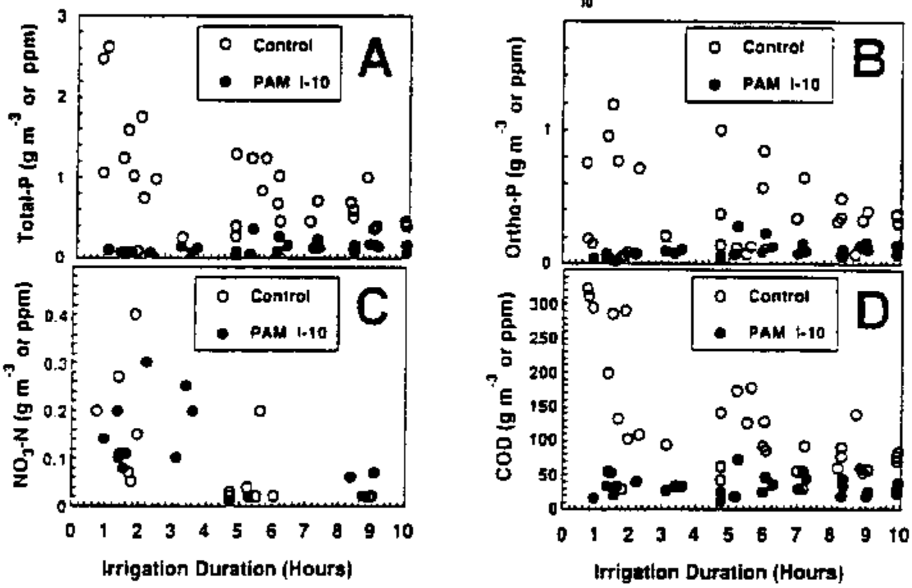
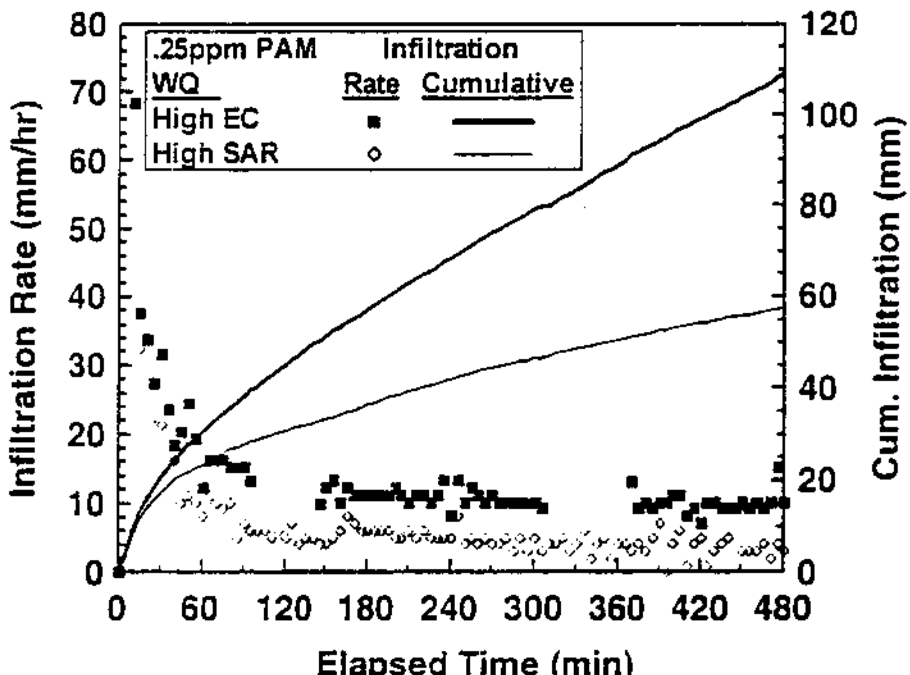


Fig. 4 The effect of source water-quality on furrow infiltration rate and cumulative infiltration of PAM C_1-treated furrows. The effect of increasing electrical conductivity (EC) and sodium adsorption ration (SAR) of a furrow-infiltrometer water source is whown for newly formed furrows. Data from low-EC/low-SAR (unadultered Snake R.) water was intermediate to that of the other treatments, and was not shown in the interest of clarity.



References

American Public Health Association, American Water Works Association, Water Pollution Control Federation. 1971. Oxygen demand (chemical), pp. 495-499. In Standard Methods for the Examination of Water and Wastewater, ed. 13 American Public Health Association, New York.

Barvenik, F.W. 1994. Polyacrylamide Characteristics Related to Soil Applications. Soil. Sci. 158:235-243.

Barvenik, F.W., R.E. Sojka, R.D. Lentz, F.F. Andrawes, and L.S. Messner. Fate of acrylamide monomer following application of polyacrylamide to cropland. In R.E. Sojka and R.D. Lentz (ed.) Managing Irrigation-Induced Erosion and Infiltration with Polyacrylamide. Proc., Twin Falls, ID. 6 -8 May 1996. Univ. of Idaho/USDA-ARS & NRCS, Kimberly, ID.

Fox, D., and R.B. Bryan. 1992. Influence of a polyacrylamide soil conditioner on runoff generation and soil erosion: field tests in Baringo District, Kenya. Soil Technology 5:101-119.

Table 5. Soil loss and net infiltration for the standard I_{10} vs. two nonstandard PAM applications, Spray and broadcast (BrdCst). Irrigations were on newly formed 176-m (577-ft) furrows. (n=6 to 9)

Parameter	PAM Treatment			
	Standard		Nonstandard	
	Control	I_{10}	Spray	BrdCst
Soil-loss (Mg ha^{-1})	2.31 c*	0.33 a	1.54 b	0.66 ab
Net Infiltration (mm)	2.90 a	3.14 ab	2.70 a	3.83 c

*similar letters across rows indicate nonsignificant differences ($P < 0.05$).

Table 6. Mean soil loss per irrigation from furrows irrigated with typical inflows (23 L min-1 or 6 gpm) vs. doubled inflows (46 L min-1 or 12 gpm).

Parameter	PAM Treatment			
	1x Inflow		2x Inflow	
	Control	I_{10}	Control	I_{10}
Soil-loss (Mg ha^{-1})	0.64	0.08	1.90	0.15
(Standard Deviation)	(0.2)	(0.15)	(0.1)	(0.1)

bly change PAM's erosion control effectiveness (Table 6). Seasonal soil loss reduction was 89% for the 1x-inflow treatment and 93% for the 2x-inflow rate, and the difference was not significant. Thus PAM gives furrow irrigators a new option, they can increase furrow inflows, permitting more uniform water applications and potentially improving crop quality and productivity. Without PAM, inceasing furrow inflows caused intolerable furrow erosion.

PAM/water-quality interactions. The influence of irrigation-water EC and SAR was observed in both the furrow infiltration rate and cumulative infiltration. Increasing the SAR of $C_{0.25}$-amended Snake River inflows (low EC/low SAR source), from 0.7 to 9 resulted in decreased infiltration rates (Fig 4). Increasing the EC of Snake River water tended to produce higher infiltration rates for PAM-treated $C_{0.25}$ waters, although EC effects varied depending on the water's SAR. Our results suggest that changes in water quality will influence PAM's irrigation impacts. Since water quality can differ appreciably depending on source, geographic location and season-of-use, source-water chemistry should be a consideration in any PAM-application program.

Fate of applied PAM. PAM concentration in treated furrow runoff and tailwater depended upon the form of PAM applied (dry vs. solution), application strategy, time during the irrigation and sequence of irrigation. Note that noncontinuous PAM treatments in these two studies were longer than typical, ie. extended beyond furrow advance, so that all furrows could be measured simultaneously during the later sampling times, and to provide more uniform tailwater conditions among the irrigations.

Although both dry and solution PAM applications did an excellent job controlling erosion, PAM losses for the two treatments differed appreciably. PAM runoff losses of Dry $I_{10,170\%}$ were 5% of the total applied, compared to 3% losses for the solution $I_{10,170\%}$ treatment. If only the furrow advance had been treated, PAM losses for the solution I_{10} would have been 1%, compared to 3% for the Dry I_{10} treatment. Hence, the PAM application recommended in the National Resource Conservation Service Practice Standard, solution $I_{10,100\%}$, did produce the least PAM loss. During PAM injection, runoff from solution-treated furrows contained 6-10 g m^{-3} (ppm) PAM, while runoff from Dry I_{10} furrows contained 1-6 g m^{-3} (ppm). Despite the lower PAM concentration, total PAM losses were greater in Dry I_{10} furrows. The dry PAM added to the Dry I_{10} gated pipe apparently did not completely dissolve. This explains why PAM concentrations were lower in the Dry I_{10} furrow streams than in the solution-treated streams during application. The undissolved PAM masses present in the Dry I_{10} gated pipe continued supplying PAM to the flows, even after the dry PAM application had ceased. Thus, PAM was lost in Dry I_{10} runoff throughout the entire irrigation.

In early irrigations on newly formed furrows, and while injection was occurring, the dissolved PAM-content in C_1 furrow-streams declined with distance downstream, whereas, PAM concentration in I_{10} furrow streams decreased only slightly with downstream distance (Fig. 5). In later sets on previously irrigated furrows, this PAM-decline with distance was more gradual for C_1 furrows, but remained similar to early irrigations for I_{10} furrows (Fig. 6). Within one-half hour after PAM injection in I_{10} furrows ceased, the dissolved PAM concentration in furrow streams had decreased to < 0.25 g m^{-3} (ppm). This was true for both new and repeat irrigated furrows. There was some indication in one irrigation that I_{10} stream PAM-content increased slightly late in the irrigation (Fig. 5). No PAM was being applied at this time, indicating that either this was a sampling or analytical error, or that previously applied PAM was being released back into the stream. Yet, PAM is irreversibly adsorbed to soil *(Malik et al., 1991)*. Perhaps more PAM was applied to furrows than was required to saturate the soil surface. The excess polymer may have temporarily bonded to the PAM already coating the furrow perimeter, only to be released later in the irrigation set.

In the tailwater ditch, flows from I_{10}, C_1, and control furrows mixed together. The combined flows in the early irrigation resulted in a PAM concentration of about 0.5 g m^{-3} (ppm) at the tail-ditch top (Fig. 5). If this was a dilution effect only, the concentration should have been at least 3 g m^{-3} (ppm). Apparently, aqueous PAM was binding to, and flocculating the sediment contributed by control furrows, and hence was removed from the flow. Data from tail and waste water ditches indicate that, early in the irrigations, relatively higher PAM inflow concentrations drop to zero with distance downstream (Figs. 5 & 6). But, as the season progresses, the rate of decrease with distance declines (Fig 6). Thus, PAM concentration in the tail ditch had dropped below the mean detection limit at a point 93 m (300 ft) downstream of the field early in the season, and 530 m (1700 ft) downstream, late in the season.

Conclusions

PAM is an excellent soil erosion deterrent for furrow irrigated fields. It is a cost effective and safe technology, when used at the rates employed in these studies, and greatly reduces both sediment and chemical loading in agricultural runoff. The PAM employed was a moderate-charge-density (18% hydrolysis) anionic form with a molecular weight of 12-15 Mg mol^{-1}. When applied at rates greater than 0.7 kg ha^{-1}, PAM-treated irrigation water reduced furrow soil loss by an average 94% (80-99%) and increased net infiltration by an average 15%. Consistent control occurred when application rates were above 0.7 kg ha^{-1}. PAM reduced soil erosion losses well below soil-loss-tolerance limits on slopes ranging from 0.5 - 3.5%. A very effective approach added 10 g m^{-3} PAM to the irrigation water at the start of the set, continuing during or slightly beyond the furrow advance period.

Acknowledgements

This work was supported in part by the Cooperative Research and Development Agreement with CYTEC Industries under contract 58-3K95-4-216.

Mention of trademarks, proprietary products or vendors does not constitute a guarantee or warranty of the product by the University ofIdaho or USDA-Agricultural Research Service and does not imply its apporval to the exclusion of other products or vendors that may also be suitable.

Fig. 3 Total-P (A), Ortho-P (B), NO_3-N (C) and chemical oxygen demand, COD (D) concentrations in runoff water from control and PAM I_{10}-treated furrows.

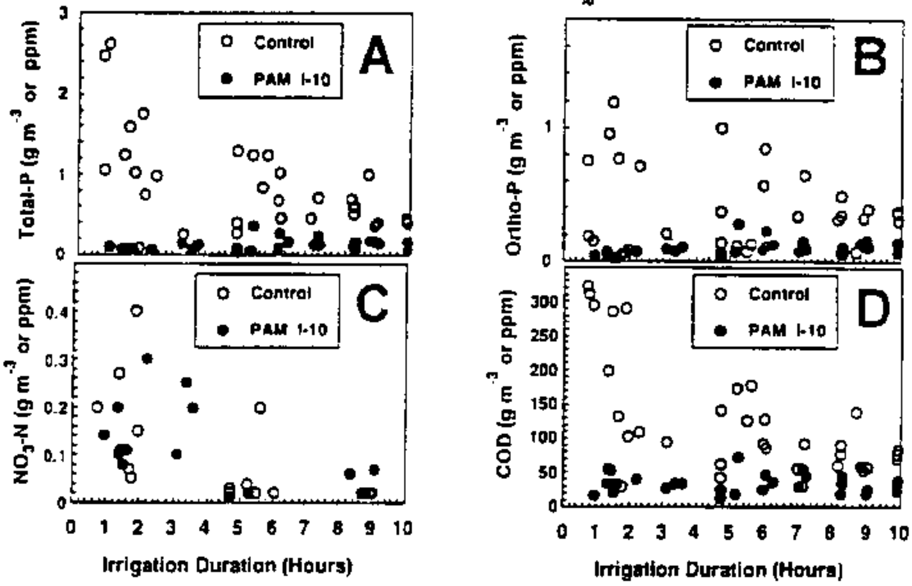
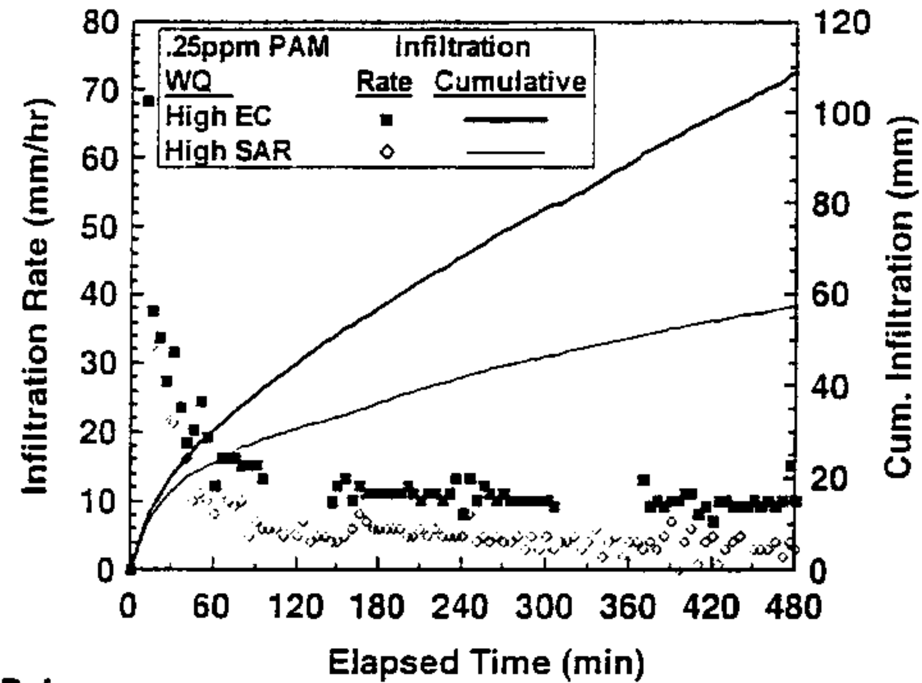


Fig. 4 The effect of source water-quality on furrow infiltration rate and cumulative infiltration of PAM C_1-treated furrows. The effect of increasing electrical conductivity (EC) and sodium adsorption ration (SAR) of a furrow-infiltrometer water source is whown for newly formed furrows. Data from low-EC/low-SAR (unadultered Snake R.) water was intermediate to that of the other treatments, and was not shown in the interest of clarity.



References

American Public Health Association, American Water Works Association, Water Pollution Control Federation. 1971. Oxygen demand (chemical), pp. 495-499, In Standard Methods for the Examination of Water and Wastewater, ed. 13 American Public Health Association, New York.

Barvenik, F.W. 1994. Polyacrylamide Characteristics Related to Soil Applications. Soil. Sci. 158:235-243.

Barvenik, F.W., R.E. Sojka, R.D. Lentz, F.F. Andrawes, and L.S. Messner. Fate of acrylamide monomer following application of polyacrylamide to cropland. In R.E. Sojka and R.D. Lentz (ed.) Managing Irrigation-Induced Erosion and Infiltration with Polyacrylamide. Proc., Twin Falls, ID. 6 -8 May 1996. Univ. of Idaho/USDA-ARS & NRCS, Kimberly, ID.

Fox, D., and R.B. Bryan. 1992. Influence of a polyacrylamide soil conditioner on runoff generation and soil erosion: field tests in Baringo District, Kenya. Soil Technology 5:101-119.

Fig. 5 PAM concentration in I_{10} and C_1 furrows and tail and waste water ditches for irrigation three, on newly formed furrows. PAM content in streams are shown for three different sampling times. and at several positions in furow and tail water

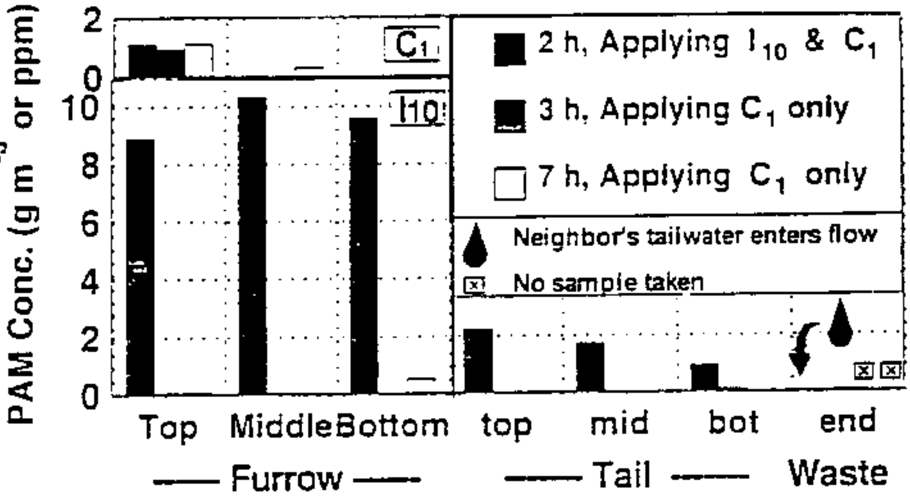
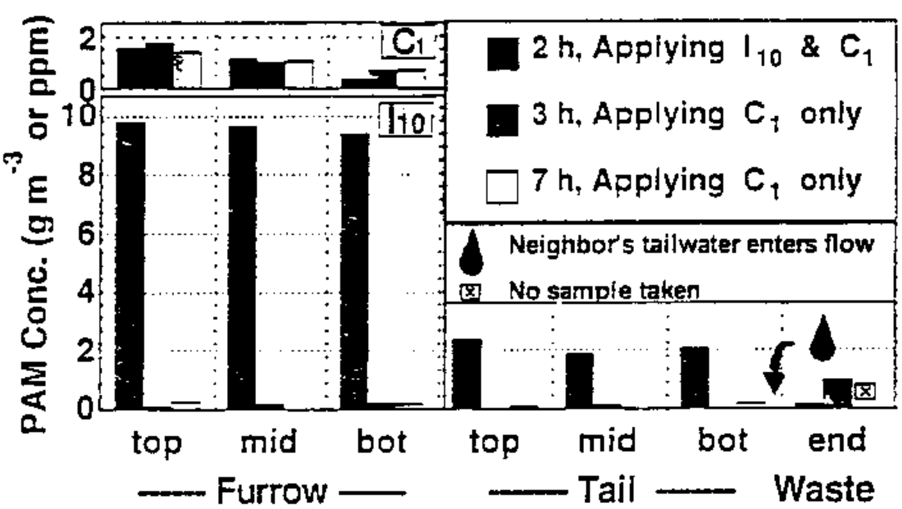


Fig. 6 PAM concentrations in I_{10} and C_1, furrows and tail and waste wate ditches for irrigation four, a repeat irrigation on furrows previously irrigated, and without an intervening cultivation. PAM content in streams are shown for three different sampling times, and at several positions in furrow and tailwater ditches.



Greenberg, A.E., L.S. Clesceri, and A.D. Eaton (ed.) 1992. Standard methods for the Examination of Water and Wastewater. 18th ed. Am. Public Health Assoc., Washinton, DC. P4-112

Kay-Shoemake, J.L. and M.E. Watwood. 1996. The Role of amidase in Microbial utilization of PAM as an N-source. In R.E. Sojka and R.D. Lentz (ed.) Managing Irrigation-Induced Erosion and Infiltration with Polyacrylamide. Proc. , Twin Falls, ID. 6 -8 May 1996. Univ. of Idaho/ USDA-ARS & NRCS, Kimberly, ID.

Lentz, R.D. 1996. Irrigation (Agriculture): Using Polyacrylamide to Control Furrow-Irrigation Induced Erosion. pg. 162-165. In S.P. Parker (ed.) 1996 Yearbook of Science and Technology. McGraw-Hill, Inc., New York.

Lentz, R.D. and R.E. Sojka. 1994a. Field Results Using Polyacrylamide to Manage Furrow Erosion and Infiltration. Soil. Sci. 158:274-282.

Lentz, R.D. and R.E. Sojka. 1994b. Automated Imhoff Cone Calibration and Soil Loss/Infiltration Analysis for Furrow Irrigation Studies. p. 858-863. In D.G. Watson, F.S. Zazueta, and T.V. Harrison (eds.) Computers in Agriculture 1994: Proceedings of the 5th International Conference on Computers in Agriculture, Orlando, FL. 5-9 Feb. 1994. ASAE, St. Joseph, MI.

Lentz, R.D. and R.E. Sojka. 1996. PAM conformation effects on furrow erosion mitigation efficacy. In R.E. Sojka and R.D. Lentz (ed.) Managing Irrigation-Induced Erosion and Infiltration with Polyacrylamide. Proc. , Twin Falls, ID. 6 -8 May 1996. Univ. of Idaho/USDA-ARS & NRCS, Kimberly, ID.

Lentz, R.D., I. Shainberg, R.E. Sojka and D.L. Carter. 1992. Preventing Irrigation Furrow Erosion With Small Applications of Polymers. Soil Sci. Soc. Am. J. 56:1926-1932.

Lentz, R.D., R.E. Sojka and D.L. Carter. 1993. Influence of Polymer Charge Type and Density on Polyacrylamide Ameliorated Irrigated Furrow Erosion. p. 547. In Anon. (ed.) Preserving Our Environment-The Race is On: Proc. XXIV International Erosion Control Association Conf. Indianapolis, IN, 23-26 Feb. 1993. International Erosion Control Association, Steamboat Springs, CO.

Lentz, R.D, R.E. Sojka, B.J. Prater, J.A. Foerster, and R.E. Peckenpaugh. 1995. Polyacrylamide concentration changes and mass balance along treated, irrigated furrows. p 295 In Agronomy Abstracts. ASA, Madison, WI.

Lentz, R.D., R.E. Sojka, and J.A. Foerster. 1996. Estimating polyacrylamide concentration in irrigation water. J. Environ. Quality 25:xx-xx (In Press).

Lentz, R.D., R.E. Sojka, and C.W. Robbins. 1996. Reducing phosphorus losses from surface irrigated fields. In Agronomy Abstracts. ASA, Madison, WI. [Presented at the ASA/ CSSA/SSSA meetings, Indianapolis, IN, 3-8 Nov., 1996]

Lentz, R.D., T.D. Stieber and R.E. Sojka. 1995. Applying Polyacrylamide (PAM) to Reduce Erosion and Increase Infiltration under Furrow Irrigation. p. 79-92. In L.D. Robertson, P. Nolte, B. Vodraska, B. King, T. Tindall, J. Romanko and J. Gallian (eds.) Proc. Winter Commodity Schools - 1995. Vol. 27. University of Idaho Cooperative Extension, Moscow, ID.

Malik, M., A. Nadler, and J. Letey. 1991. Mobility of polyacrylamide and polysaccharide polymer through soil materials. Soil Tech. 4:255-263.

Roa, A., 1996. Screening of polymers to determine their potential use in erosion control on construction sites. In R.E. Sojka and R.D. Lentz (ed.) Managing Irrigation-Induced Erosion and Infiltration with Polyacrylamide. Proc. , Twin Falls, ID. 6 -8 May 1996. Univ. of Idaho/USDA-ARS & NRCS, Kimberly, ID. (In Press)

Robbins, C.W. and C.L. Wiegand. 1990. Field and laboratory measurements. p. 201-219. In K.K. Tankji (ed.) Agricultural Salinity Assessment and Management. ASAE, New York, NY.

Sojka, R.E. and R.D. Lentz. 1993. Improving water quality of return flows in furrow-irrigated systems using polymer-amended inflows. p. 395-397. In Agricultural Research to Protect Water Quality Conference Proceedings, Minneapolis, MN. 21-24 Feb. 1993.

Sojka, R.E. and R.D. Lentz. 1994. Polyacrylamide (PAM): A new weapon in the fight against Irrigation-induced erosion. USDA-ARS Northwest Irrigation and Soils Research Laboratory, Station Note #01-94.

Sojka, R.E. and R.D. Lentz. 1996. A PAM primer: A brief history of PAM and PAM-issues related to irrigation. In R.E. Sojka and R.D. Lentz (ed.) Managing Irrigation-Induced Erosion and Infiltration with Polyacrylamide. Proc. , Twin Falls, ID. 6 -8 May 1996. Univ. of Idaho/USDA-ARS & NRCS, Kimberly, ID.

Sojka, R.E., R.D. Lentz and J.A. Foerster. 1994. Software utilizing Imhoff cone volumes to estimate furrow-irrigation erosion. J. Soil Water Cons. 49:400-406.

Trout, T.J., R.E. Sojka and R.D. Lentz. 1995. Polyacrylamide Effect On Furrow Erosion and Infiltration. Trans. ASAE 38:761-765.

Watanabe, F.S. and S.R. Olsen. 1965. Test of an ascorbic acid method for determining phosphorus in water and $NaHCO_3$ extracts from soils. Soil Sci. Soc. Am. Proc. 29:677-678.

Watwood M.E. and J.L. Kay-Shoemake. 1996. Microbial ecology of polyacrylamide application in agricultural soils. In R.E. Sojka and R.D. Lentz (ed.) Managing Irrigation-Induced Erosion and Infiltration with Polyacrylamide. Proc. , Twin Falls, ID. 6 -8 May 1996. Univ. of Idaho/USDA-ARS & NRCS, Kimberly, ID.

About the authors

Lentz and Sojka are soil scientists with the USDA-Agricultural Research Service, Northwest Irrigation and Soils Research Laboratory, 3793N 3600E, Kimberly, ID 83341.